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ΤΙΤΛΟΣ

HOW KINEMATIC CHARACTERISTICS AFFECT 60M SPRINT PERFORMANCE

της

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Μεταπτυχιακή Διατριβή που υποβάλλεται στο καθηγητικό σώμα για τη μερική εκπλήρωση των υποχρεώσεων απόκτησης του μεταπτυχιακού τίτλου του Προγράμματος Μεταπτυχιακών Σπουδών «Άσκηση και Υγεία» του Τμήματος Επιστήμης Φυσικής Αγωγής και Αθλητισμού του Πανεπιστημίου Θεσσαλίας.

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ΠΩΣ ΤΑ ΚΙΝΗΜΑΤΙΚΑ ΧΑΡΑΚΤΗΡΙΣΤΙΚΑ ΕΠΗΡΕΑΖΟΥΝ ΤΗΝ ΕΠΙΔΟΣΗ ΤΩΝ 60Μ ΣΠΡΙΝΤ

Η ταχύτητα είναι μια πολύ σημαντική κινητική ικανότητα η οποία καθορίζει την καλή επίδοση σε πολλά αθλήματα. Σκοπός αυτής της έρευνας ήταν να εξετάσει μια μέθοδο αξιολόγησης της επίδοσης των 60μ σπριντ με την χρήση ενός επιταχυνσιόμετρου καθώς επίσης και να εξετάσει τα κινηματικά χαρακτηριστικά (μήκος και συχνότητα διασκελισμού, χρόνος πτήσης, χρόνο επαφής, έκκεντρος και τον ομόκεντρος χρόνος επαφής) κατά την διάρκεια των 60μ σπριντ. Δέκα αθλητές στίβου (ηλικία:17.8±3.12) πραγματοποίησαν 3 μέγιστες προσπάθειες στα 60μ σπριντ με 6 λεπτά διάλειμμα μεταξύ κάθε προσπάθειας. Για την καταγραφή των επιμέρους χρόνων κατά την διάρκεια των 60μ σπριντ , τοποθετήθηκαν φωτοκύτταρα κάθε 10 μέτρα, καθώς επίσης και μια κάμερα η οποία κατέγραφε τις 3 προσπάθειες κάθε αθλητή. Επίσης, ένα επιταχυνσιόμετρο τοποθετήθηκε στην κνήμη κάθε αθλητή για να καταγράφει την επιτάχυνση καθ’ όλη την διάρκεια των 60μ σπριντ. Για να εξετάσουμε την σχέση μεταξύ της επίδοσης των 60 μέτρων και των κινηματικών χαρακτηριστικών χρησιμοποιήθηκε ανάλυση συσχέτισης Pearson. Για την σύγκριση των κινηματικών μεταβλητών σε κάθε 10 μέτρα χρησιμοποιήθηκε ανάλυση διακύμανσης μονής κατεύθυνσης, ενώ χρησιμοποιήθηκε t test για ανεξάρτητα δείγματα για να εξεταστεί η επίδοση των αθλητών στην πρώτη και στην τρίτη προσπάθεια. Τα αποτελέσματα έδειξαν ότι υπήρχε ισχυρή θετική συσχέτιση, η οποία ήταν στατιστικά σημαντική ($p<.05$) μεταξύ της απόδοσης των 60μ σπριντ και του χρόνου επαφής ($r=.922$), του ομόκεντρου χρόνου επαφής ($r=.882$) αλλά όχι του έκκεντρου χρόνου επαφής ($r=.118$). Επίσης, τα αποτελέσματα έδειξαν πως υπήρχε ισχυρή συσχέτιση μεταξύ της απόδοσης των 60μ και της συχνότητας του διασκελισμού($r=.646$, $p<.05$). Ωστόσο δεν υπήρχαν στατιστικά σημαντικές διαφορές των κινηματικών χαρακτηριστικών μεταξύ της πρώτης και της τρίτης προσπάθειας, εκτός από τον χρόνο απόδοσης.

Λέξεις κλειδιά: επιτάχυνση, μέγιστη ταχύτητα, κνημιαία επιτάχυνση, συχνότητα διασκελισμών, μήκος διασκελισμού, χρόνος επαφής, έκκεντρη φάση, ομόκεντρη φάση, χρόνος πτήσης.

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How kinematic characteristics affect 60m sprint performance

Abstract

Sprint performance is one of the most important physical elements in sports' performance. The aim of the study was to examine the kinematic characteristics, stride length (SL), stride frequency (SF), flight time (FT), ground contact time (CT), eccentric (ECC CT) and concentric contact time (CON CT) during a 60m sprint. Also, to evaluate a method of sprint performance analysis by using an accelerometer devise. Ten track and field athletes (age:17.8±3.12yrs) performed 3 maximum 60m sprint trials with 6min recovery in between. An accelerometer devise used to record tibial acceleration throughout 60m sprints. Photocells recorded time performance every 10m and a video camera recorded 60m sprint trails. Pearson correlation was used to examine the relationship between kinematic characteristics and sprint performance, one-way repeated measures ANOVA was used to test comparisons in kinematic variables in every 10m and paired t test to compare differences between 1st and 3rd 60m trial. A significant strong positive correlation was found between 60m time performance and ground CT ($r=.922$, $p<.001$) and CON CT ($r=.882$, $p=.001$) but not with ECC CT ($r=.118$, $p=.746$). Also, a positive correlation was found between time performance and SF ($r=.646$, $p<.05$). There were no significant differences in kinematic characteristics between 1st and 3rd sprint trial, except for the time performance that was slower in the 3rd than the 1st sprint trail.

Key words: acceleration, maximum velocity, tibial acceleration, stride frequency, stride length, ground contact time, eccentric phase, concentric phase, flight time.

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1. INTRODUCTION

Sprint performance is crucial in many sports and especially in track and field events. During sprinting, the flight phase covers the biggest part of the stride (60%), while the remaining time is covered by the contact phase (40%). The athlete's goal is to cover a certain distance in the fastest possible time. The resulting time is the combination of the covered distance and the athlete's average velocity. The average velocity derives from the equation of the total distance divided by the time needed to cover it. The three main phases in 100m sprint are the acceleration phase, the maximum velocity phase and the deceleration phase (Mackala, 2007; Slawinski et al., 2017). Every phase can be divided into more sections. For example acceleration can be separated in initial acceleration (0-12m) and in main acceleration (12-35m) (Mackala, 2007). For the best performance rapid acceleration and high maximum velocity are the most important factors. Kinetic and kinematic characteristics in 100m sprints are also correlated with performance. Ground reaction force (GRF) is a major kinetic factor of performance, which has an effect to the runner's body and indicates linear acceleration during a total motion sprint. GRF can accelerate or decelerate the human body. The kinematic characteristics (stride length, stride frequency, flight time, contact time) affect GRF.

Acceleration

The mechanical principles of sprinting are similar to those of running in general. The only difference is that there is a large acceleration in the first 10m and after 10m. At the start of a sprint where the athlete is at starting position, horizontal acceleration is the most important factor that determines a good performance. A new method to indicate athletes' horizontal force–velocity relationship over 40m has been developed (Samozino et al., 2016). The balance between braking and propulsive impulses increases sprint velocity. Scientific literature has already supported that best performances are correlated with horizontal forces (Colyer et al., 2018; Nagahara et al., 2018). So, in sprint performance the important factors are the total horizontal force, the minimizing of braking force and the combination of braking and propulsive force. Acceleration determines final time rather than average speed. Average speed is the direct determinant of sprint performance. This principle applies

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to both accelerated running (initial 0-12m and main 12-35m) and sprinting at maximum velocity. During the development of a sprint, peak braking and propulsive forces tend to increase throughout acceleration (Nagahara et al., 2018). Other studies have indicated the same tendency (Colyer et al., 2018).

Braking and propulsive Phase of the quadricep

Muscles can generate greater forces under eccentric conditions than under isometric or concentric contraction (Reed & Bowen, 2008). During the braking phase the quadricep contracts in an ECC manner (producing force or moment which bring about decreases in SL or knee and ankle joint angles), whereas during the propulsive phase the force that is produced by quadricep is with a concentric manner (producing force or moment which bring about increases in SL or knee and ankle joint angles) (Brughelli & Cronin, 2008; Schache et al., 2015). The applied force during sprinting differs in these two phases in motor regulation. GRF is determined by SL and SF and can define vertical impulse during braking phase (Nagahara et al., 2018). To achieve a better performance we have to minimize braking force of quadricep and accordingly we could have the possibility to minimize the propulsive force produced in quadricep (Bezodis et al., 2008). According to literature, if the braking phase of quadricep is decreased, the effectiveness is applied in high level athletes but not in moderate athletes, because the improvement in performance is small (Bezodis et al., 2008). Other investigators have proved that a larger propulsive force or impulse, rather than a smaller braking force or impulse, was more important so as to achieve better sprinting performance over 40m distance or 0-20m sections of 40m sprint (Morin et al., 2015; Rabita et al., 2015). Haugen et al. (2019) supports that only the propulsive force is associated with acceleration in the horizontal direction (Hunter et al., 2004).

Stretch shortening cycle (SSC) and CT

The basic muscle function is defined as the SSC, where the preactivated muscle is first stretched (eccentric action) and then followed by the shortening (concentric) action which is activated at the ground contact phase (Lai et al., 2014). The force that the muscles generate depends on the muscle contraction. The correlation between strength and speed differ between eccentric and concentric

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muscle activity (Seow, 2013). As the contraction speed increases, concentric muscle power decreases. In contract, during eccentric activity the increase in speed leads to an increase in muscle force due to the contraction of the muscle fiber and the resistance by the connective tissue during its contraction. When contact time (CT) is faster than 0.0250 seconds, it is considered that the SSC is fast. In sprinting the SSC activity is considered fast because the sprinters' push is <0.250. The main factors that determine ground CT are the rapid application of forces to the ground, stiffness of lower limp and the biomechanics of sprint technique (Lockie et al., 2011). During the SSC elastic energy is released, which is stored in the eccentric phase and released during the concentric phase. Shorter foot contact time with the ground is generated by a more effective elastic energy.

Stride Length (SL), Stride Frequency (SF) and Flight Time (FT)

Two of the main characteristics that monitor running speed is SL and SF. To improve sprinting performance we have to achieve longer SL and higher SF, or both (Corn & Knudson, 2003; Salo et al., 2011). SF is associated with the neural factor, but SL is determined by the magnitude of GRF (Weyand et al., 2000). One of the factors determining the combination of SL and SF during sprinting is the ground reaction force (GRF)(Hunter et al., 2004). Athletes can produce higher peak ground reaction force (pGRF), propulsion and rate of force development (explosive strength) during each foot stride while running. The higher the pGRF and propulsion produced, the higher are the sprint velocities achieved (Hunter et al., 2005). There is a negative relationship between SL and SF (Hunter et al., 2004; Salo et al., 2011). Previous study has revealed that higher maximum running speed with a longer SL is achieved with greater vertical GRF during the first half (50 %) of the contact phase, rather than in the second half (Clark & Weyand, 2014). Van Schenau et al. (1994) support that to exert greater SL, greater forward propulsion has to be provided. Furthermore, the fact that FT makes up for the biggest part of the total stride time, forces runners to utillize fewer and shorter strides.

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Anthropometrics and Speed

The speed in human runners is traced to the origin of anatomic and physiological features that affect SL and SF. Previous studies have proved that slender legs in conjunction with fast muscle fibers increase SF and athletes with long limbs reached longer SL by providing greater horizontal propulsion (Jones et al., 1993; Van Schenau et al., 1994).

Sprinting Training

Sprint improvement is an interesting part to investigate as there are many training methods (resisted training, plyometrics, resisted sprinting, free sprinting) to increase its performance. Maximizing sprinting ability is very important for the athlete and their coaches.

Achieving the best performance during a sprint depends on three parameters. Firstly, on a good starting ability (acceleration ~20m), secondly on the maximum running velocity (~30-40m) and thirdly in speed maintenance (~50m). The improvement of the first phase of acceleration depends on kinematics characteristics (SF, SL, FT, CT) and on a high level of maximum power (Cronin et al., 2008; Lockie et al., 2012). In the second phase, during sprint performance, the main factors are SF and SL (Hunter et al., 2004). More powerful sprinters have short ground CT, longer SL and FT and higher SF during sprint (Kale et al., 2009). In addition, except for SL and SF, a very important parameter during sprint performance is CT. The shorter is the foot CT with the ground, the faster the sprinter is. In the foot contact phase of sprint strides, muscle force continuously changes. This is happening due to the stretch shortening cycle (SSC) and due to elastic energy, which is stored in the eccentric phase (ECC) and is released during the concentric phase (CON). A shorter foot CT with the ground produced more effective elastic energy (Ito et al., 1983).

Strength training

Sprint performance maximum gains are also affected by the subject's characteristics as age and body mass (Häkkinen et al., 1987; Seitz et al., 2014). and resistance training variables. Such as the level of practice, the frequency of

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resistance training sessions and the rest time between sets (Seitz et al., 2014). According to earlier studies, increasing lower body strength levels contributes to the improvement of sprint performance by improving the maintenance of velocity (Comfort et al., 2012; McBride et al., 2009; Seitz, et al., 2014). Furthermore, other literature has proved that there is significant correlation between back squat and 20-40m sprint (Comfort et al., 2012; McBride et al., 2009; Seitz, et al., 2014). Furthermore, variation of strength capabilities have relatively bigger roles throughout the performance of a sprint (Healy et al., 2019).

A wide accepted strength training method according to the literature is resistance training (RT) (Harries et al., 2018). The goal of RT is to improve muscle strength, the ability to generate maximum force and an increase in muscle mass (Benito et al., 2020). Numerous studies have demonstrated great improvements in Vertical Jump(VJ) using RT (Lesinski et al., 2016). Other investigators have proved, that this type of training enhances ground reaction force (GRF) and power capabilities (Kraemer et al., 2002) which are necessary for both maximum jump and sprint running. Also, there are researchers who underline the correlation of RT especially with sprints. Corn & Knudson (2003), supports that maximum muscular power correlated with mean 20, 40, and 60m velocities. All these mentioned improvements that were provoked by the use of RT are associated with enhancements in sprinting (Seitz, et al., 2014).

Plyometric training

Another effective training method which enhances both vertical jump (VJ) and sprint performance is plyometric training (PT) (Bianchi et al., 2019; Oxfeldt et al., 2019). Plyometric training is a method which utilizes body weight as resistance and employs the stretch-shortening cycle (SSC) to increase VJ performance (Argus et al., 2011). PT consists of various body weight jumps, like drop jumps (DJs), countermovement jumps (CMJs), alternate leg bounding, hopping and other SSC jumping exercises. A lot of studies have identified the benefits of PT in VJ height (Argus et al., 2011). Vertical jump tests provide evaluations for lower-limb power and give valid assessments of muscular power.

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Tibial Acceleration

Previous studies examined with the help of accelerometers what happens on tibia during running. During the athlete’s run, all fatigue fractures? occur on the tibia (Bennell et al., 2004). Running technique, running velocity and stiffness in lower limbs affect tibial accelerations (Sheerin et al., 2019). When the foot strikes the ground, the velocity is reduced to zero and a large ground reaction force (GRF) is generated (Whittle, 1999). GRF represents the total body acceleration, as a result, peak tibial acceleration (TA) corellated significantly with GRF. There is literature which supports that peak of TA correlated with the rate of vertical GRF (Greenhalgh et al., 2012). To minimize error, we have to be careful with the attatchement method, the placement location and the signal of the sensor. Accelerometers’ size and weight is relatively small. TA acceleration measured by an accelerometer attached on tibia, is the mass acceleration due to gravity, rather than velocity alteration relative to time (Nigg et al., 1995). Also, sensors that transmit wireless can cause delays on signal or a complete dropout.(Nigg et al., 1995).

Aim of the study

The aim of this study is to analyze parameters during 60m sprinting by using an accelerometer devise. Specifically, to determine kinematic characteristics (SF, SL, CT, CON CT, ECC CT, FL) of every 10m section during the 60m sprint. Finding the effect of each of the above parameters on sprint performance will help coaches to assess their athletes and to develop a more effective speed training program.

Hypothesis of this study

- The performance of 60m depends on kinematic characteristics.
- The performance of 60m depends on kinematic characteristics of every section during 60m sprint.
- There is correlation between kinematic characteristics in the final performance.
- There are differences between the first and the third trial in kinematic characteristics.

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- There is a correlation between anthropometrics and kinematic characteristics which influence total performance.

2. METHODS

Participants

The study was conducted with a sample of two male and eight female track and field athletes (age: 17.8±3.12yrs, body mass: 61.73±7.56kg, body fat (skinfold): 12.6±0.04%, body height: 1.71±0.09m, arm length: 1.7±0.12m right, leg length: 0.91±0.05m, left leg length: 0.91±0.05m (table 1.). The sum of the athletes in the past 3 years, participated consistently in national track and field events, as sprinters and jumpers, with 3 of them competing in international level events. All athletes had at least 3 years of sprint training experience, so they were familiar with the start position.

Sampled athletes did not have any recent injuries or any medical problem. They were informed of all the risks and benefits associated with the and they agreed to the terms of participation. The study was conducted after the approval of the University of Thessaly ethics committee.

	Age (yrs)	Body Height (m)	Body Mass (kg)	BMI	Arm Length (m)	Right Leg Length (m)	Left Leg Length (m)	Body Fat (%)
Mean	17.8	1.71	61.73	21.05	1.7	0.91	0.91	12.61
STDEV	3.12	0.09	7.56	1.56	0.12	0.05	0.05	0.04

Table 1. Athletes' anthropometric measurements.

Procedure

The measurements took place at the municipal stadium in Trikala. The experiment consisted 2 sessions:

The 1st session included all anthropometric measurements (body mass, body fat, body height, arm length, leg length). Body mass was measured using the standard scale (Seca, 777), generating the participant's total kilograms. Body fat was calculated utilizing the measurements of seven skin folds (chest, sub scapilar,

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triceps, sub scapula, abdominal, suprailiac, quadriceps, bicep brachii). We used SIRI equation (0,00043499*SUMSKIN) + (0,00000055*SUMSKIN^2) - (0,00028826*AGE) and in order to calculate BM we used % body fat = (495/ BODY DENSITY)-450. Body height was measured using a standard tape. Arm Length was deducted by using the measurement from the acromiale (lateral edge of the acromion process, e.g., bony tip of shoulder) to the tip of the little finger. Leg length was measured from the umbilicus to the medial malleoli of the ankle. The sum of the stated measurements was used to determine the anthropometric profile of each of the participants.

In the 2nd session 60m sprint performance was recorded every 10m by using photocells. Also, tibia acceleration was measured by attaching an accelerometer to the athletes' tibia. A camera placed at 30m was recording every participant's attempt to validate our data. The participants performed warm up (~30minutes duration) consisted of 10 min low intensity running (jogging), stretching and joint mobility exercises, skipping and strides, similar to what they did before a competition. After warm up, athletes completed 3 maximal efforts at 60m sprint with standing start with 6min rest between trails. We also, measured: stride length, stride frequency, running eccentric and concentric ground contact time, during sprinting.

Data processing:

Timing Gates: All the sprints were performed in a 60m indoor synthetic track surface. Photocells (Optojump Microgate, Italy) were set up in every 10 meters, at 10m, 20m, 30m, 40m, 50m and 60m, to record split times during a 60m sprint. Timing gates were also marked across the lane with white lines (white tape). The time of every 10m was calculated by subtracting the previous split time from the split time in every mark. Also, the average speed (u) was calculated by the formula:

$$u = \frac{60m}{t}$$

Accelerometer position placement: We attached *a triaxial* accelerometer (XSENS, Holland) directly to the tibial bone to estimate TA (Lafortune & Hennig, 1991). The accelerometer's sample frequency was set at 120Hz. The accelerometer was connected wirelessly to a PC (photo 1).

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Photo 1. *Accelerometer position placement*

We used the accelerometer's data, video analysis and photocells to create a full evaluation of the 60m sprint. Firstly, we used the data of the accelerometer to create charts with acceleration being the X axis and the time being the Y axis. We defined the chart's starting point (Y=0 and X=0) as Y=9,81m/s^2 due to the Earth's gravity and X=0 as the point when the movement begins. We create a new chart with the time and the new Acc X. To calculate the reaction time which the accelerometers does not measure, we used video analysis, thus correcting the charts' values, and synchronizing it with the video. Then, we had the stride frequency depicted in the chart in every 10 meters, confirmed by the video analysis. Also, by having the SF in every ten meters, we were able to calculate the mean of SL in every 10m by dividing the frequency with the distance in every 10m. To define the starting and the ending points of eccentric and concentric phase during sprinting and to determine total ground contact time in every stride, we first synchronized a camera (Vicon, T-series,Oxford,UK), a force plate (Bertec, 4060-15) and the accelerometer in the lab. To calculate the total CT, we summed the time of

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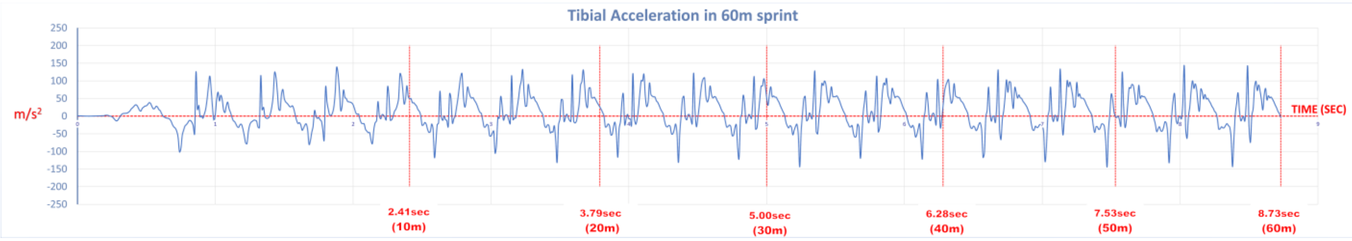
the eccentric and concentric CT in every step, and we summed the CT of all the steps. Having the total CT during 60m we calculate the total flight time by subtracting the CT from the total 60m time. Our methodology of splitting the 60m sprint to 10m marks enabled us to have all the values for all the individual parameters, thus creating a complete image of the 60m sprint with detailed findings in every 10m mark.



Graph 1. Tibial acceleration and time performance every 10m during 60m sprint.

Video Analysis: In the middle (30m) of the 60m we placed a camera to record every trial.

Stride Length and Frequency: We determined stride frequency in every 10m by using video analysis and the mean stride length by dividing 10m times with the stride frequency. We additionally, confirmed stride frequency by using the accelerometer's data.

Flight time: We estimated mean flight time of strides during every 10m, by subtracting the strides' total contact time from the time performed during the 10m and then divided by the number of strides.

Muscle contraction of quadricep: We defined as eccentric phase of the quadricep the braking phase, where the muscle lengthens under tension and as concentric phase, the propulsive phase when the muscle shortens. To define the starting and the ending points of eccentric and concentric phase during sprinting and to determine total ground contact time in every stride, we first synchronized a camera (Vicon, T-series,Oxford,UK), a force plate (Bertec, 4060-15) and the accelerometer in the lab. The starting and the ending points of eccentric and

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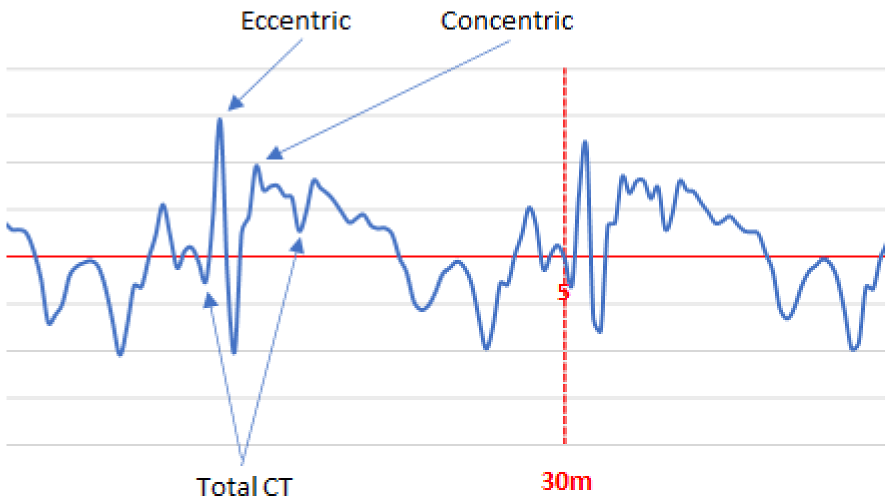
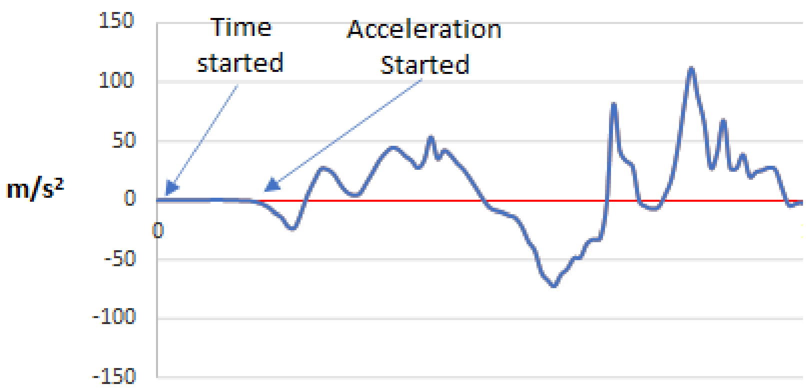
concentric phase as determined in the lab and then in the track are presented in graph 2.



Graph 2. Definition of eccentric and concentric ground contact time

Reaction time: The acceleration data from the point where time started to the point where athletes started to move was defined as the reaction time. To calculate the reaction time, we subtracted the time recorded from the point that tibial acceleration started at the 10m photocell gate from the time recorded at 10m photocell (graph 3).



Graph 3. Estimation of reaction time.

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Statistical analysis

The statistical analysis of the sprint parameters was done using the IMB SPSS 26 (SPSS, Inc., Chicago, IL, USA). The significance level was set at 0.05. The data was presented as mean±SD.

One-way repeated measures ANOVA was used to test if there is significant difference in kinematic variables during 60m sprint between the 1st 10m, the 2nd 10m, the 3rd 10m, the 4th 10m, the 5th 10m and the 6th 10m.

To test the first hypothesis, that performance in 60m is correlated with stride length, stride frequency, flight time and ground contact time, Pearson correlations were employed. Data normality was checked using the Shapiro-Wilk test, which showed that all variables at 1st trial, follow a normal distribution. However, in the 3rd trial some variables do not follow normal distribution and the Spearman correlation were employed. To test one of the hypothesis, whether anthropometrics affect performance in 60m, we also employed Pearson correlation, as we also checked our data using Shapiro-Wilk test.

To compare every parameter between the 1st and the 3rd trial we use the paired samples t test.

3. RESULTS

Correlations

<u>1st Trial</u>

The Pearson correlation analysis revealed a statistically significant positive correlation between 60m time performance and SF (r=.646, p<0.05) and FT (r=.861, p=0.01). However, no significant correlation was found with SL (r=-.677, p=0.053).

It was found that SF has strongly high negative correlation with SL (r=-.997 p<0.01) (graph4). Also, SF had high positive correlation with total CT (r=.658, p<0.05) and CON CT (r=.650 p<0.05), but there was no correlation with ECC CT (r=-.014 p=.969).

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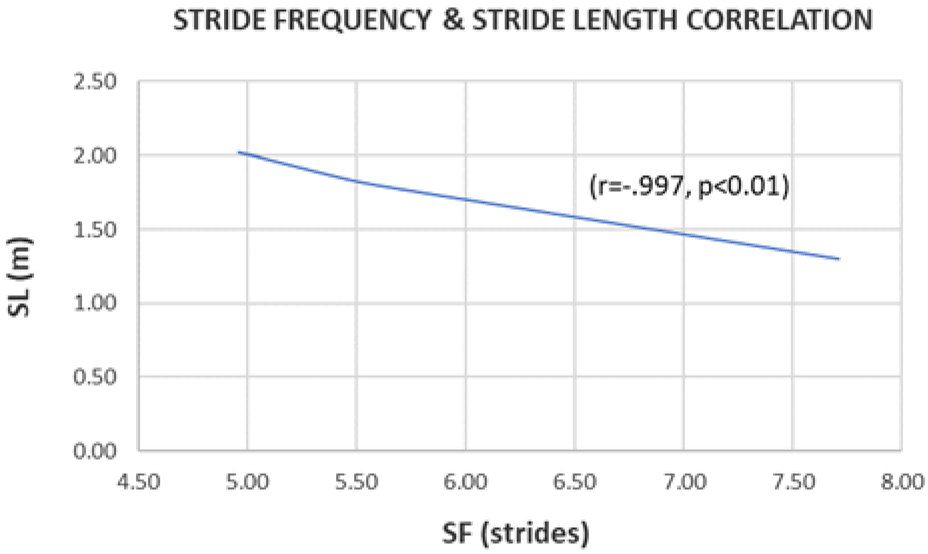

Graph 4. Correlation between stride length and stride frequency during a 60m sprint.

Correlation analysis showed a very high positive correlation between SF and 2nd 10m ($r=.712$, $p<0.05$), 3rd 10m ($r=.638$, $p<0.05$), 4th 10m ($r=.699$, $p<0.05$), 5th 10m ($r=.632$, $p=0.05$) and 6th 10m ($r=.694$, $p<0.05$). There was no statistically significant correlation between SF and 1st 10m ($r=.464$, $p=.177$).

The results showed that SL has a high negative correlation with total CT ($r=-.657$ $p<0.05$) and CON CT ($r=-.634$, $p<0.05$). SL had high negative correlation with 2nd 10m ($r=-.696$ $p<.05$) with 4th 10m ($r=-.691$, $p<0.05$) and with 6th 10m ($r=-.679$, $p<0.05$).

Results indicated that 60m time performance is positively correlated with total CT ($r=0.922$, $p<0.01$) and CON CT ($r=.882$ $p=0.01$). However, no significant correlations were found with ECC CT ($r=.118$, $p=.746$). The results indicate that those who had better time at 60m had also better concentric phase and total contact time.

Total CT had very high positive correlation with CON CT ($r=.910$, $p<,01$) and between the 1st 10m ($r=.858$, $p<0.01$), the 2nd 10m ($r=.857$, $p<.01$), the 3rd 10m ($r=.902$, $p<.001$), the 4th 10m ($r=.928$, $p<.001$), the 5th 10m ($r=.892$, $p=0.001$) and the 6th 10m ($r=.953$, $p<.001$). CON CT has very high positive correlation with the 1st 10m ($r=.836$ $p<0.01$), the 2nd 10m ($r=.857$, $p<0.01$), the 3rd 10m ($r=.873$, $p=.001$), the 4th 10m ($r=.820$, $p<0.01$), the 5th 10m ($r=.880$, $p=.001$) and the 6th 10m ($r=.887$, $p=.001$).

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The correlation analysis reveals no statistically significant relation between ECC CT and the other variables. The correlation between ECC CT and CON was ($r=-.178$, $p=623$).

FT had a high positive correlation with the 1st 10m ($r=.856$ $p<0.01$), the 2nd 10m ($r=.891$, $p=.001$), the 3rd 10m ($r=.820$, $p<0.01$), the 4th 10m ($r=.804$, $p<0.01$) , the 5th 10m ($r=.884$, $p=.001$) and the 6th 10m ($r=.776$, $p<0.01$). However, there was no significant correlation between FT and CT ($r=.600$, $p=.067$).

A correlation was found between 60m time performance and all 10m distances during the 60m. Statistical analysis showed a very high positive correlation with 1st 10m ($r=.961$ $p<0.01$), the 2nd 10m ($r=.969$, $p<0.01$), the 3rd 10m ($r=.973$, $p<0.01$), the 4th 10m ($r=.969$, $p<0.01$), the 5th 10m ($r=.991$, $p<0.01$) and the 6th 10m ($r=.981$, $p<0.01$).

Also, the results showed that the 1st 10m correlated with the 2nd 10m ($r=.892$, $p=.001$), the 3rd 10m ($r=.932$, $p<.001$), the 4th 10m ($r=.897$, $p<.001$), the 5th 10m ($r=.954$, $p<.001$) and the 6th 10m ($r=.911$, $p<.001$).

The 2nd 10m correlated with the 3rd 10m ($r=.933$, $p<.001$), the 4th 10m ($r=.948$, $p<.001$), the 5th 10m ($r=.970$, $p<.001$) and the 6th 10m ($r=.941$, $p<.001$).

Also, the results showed that the 3rd 10m correlated with the 4th 10m ($r=.908$, $p<.001$), the 5th 10m ($r=.950$, $p<.001$) and the 6th 10m ($r=.968$, $p<.001$).

The 4th 10m correlated with the 5th 10m ($r=.958$, $p<.001$) and the 6th 10m ($r=.961$, $p<.001$) and the 5th 10m correlated with the 6th 10m ($r=.961$, $p<.001$).

3rd Trial

Normality was checked using the Shapiro-Wilk test, which showed that most variables, except for the total time of 60m, FT, the 2nd 10m and the 6th 10m, follow normal distribution. To test the 1st hypothesis, that performance of 60m is correlated with stride length, stride frequency and flight time, Spearman correlations were employed. Spearman correlation analysis revealed no significant correlation between 60m time performance and SF ($r=.571$, $p=.085$), SL ($r=-.503$, $p=.138$) or FT ($r=.127$, $p=.726$)

Spearman correlation indicated that 60m time performance is correlated with contact time, concentric and eccentric phases. Results shows very high positive

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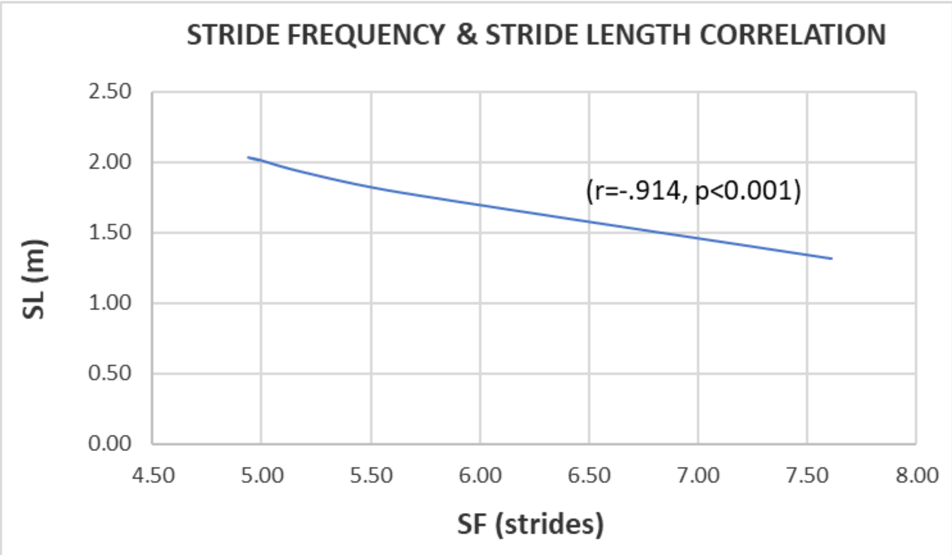
correlation with total CT (r=.915, p<.001), CON CT (r=.733, p<.01). However, no significant correlations were found with ECC CT (r=.491 p=.150).

Correlation analyses show very high positive correlation between total time in 60m and all parts of 10m with the 2nd 10m (r=.939, p<0.01), the 6th 10m (r=.933, p<0.01), the 5th 10m (r=.875, p=0.01), the 4th 10m (r=.821, p<.01), the 3rd 10m (r=.809, p<.01) and weaker with the 1st 10m (r=.685, p<.05).

It was found that SF has very high negative correlation with SL (r=-.914, p<0.001) (graph 5). However, SF had no significant correlation with total CT (r=.472 p=.168), CON CT (r=.620 p=.056), ECC CT (r=.153, p=.672) and FT (r=.129, p=723).

Correlation analysis showed very high positive correlation between SF and the 3rd 10m (r=.868, p=0.001), 6th 10m (r=.753, p<.01).



Graph 5. Correlation between stride length and stride frequency during a 60m sprint.

The results showed that SL had high negative correlation with the 3rd 10m (r=-.833 p<.01) and the 6th 10m (r=-.683 p<.01). However, there is no significant correlation with total CT (r=-.539, p=.108), CON CT (r=-.503, p=138) and ECC CT (r=-.297, p=405), FT (r=.067, p=.855) with the 1st 10m (r=.042, p.907) the 2nd 10m (r=-.354, p=.316) with the 4th 10m (r=-.073, p=.841) and with the 5th 10m (r=-.620, p=.056).

Total CT had very high positive correlation with CON CT (r=.733 p<.05). Also, the results showed high positive correlation between total CT and the 2nd 10m

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(r=.811 p<.01), with the 3rd 10m (r=.736, p<.05), the 4th 10m (r=.748, p<.05), the 5th 10m (r=.930, p<.001) and the 6th 10m (r=.848, p<.01). However, there is no significant correlation with ECC CT (r=.576, p=.082) and with FT (r=-.127, p=.726) and 1st 10m (r=.600, p=.067).

CON CT had very high positive correlation with the 2nd 10m (r=.738, p<05), the 3rd 10m (r=.766, p=.01) and the 6th 10m (r=.799, p<.001). The correlation analysis reveals no statistically significant relation between ECC CT (r=.006, p=.987), FT (r=.127, p=.726), the 1st 10m (r=.552, p=.098), the 4th 10m (r=.584, p=.077) and the 5th 10m (r=.608, p=.062).

The ECC CT and FT had no significant correlation with any of all variables.

Also, the results showed that the 1st 10m have very high positive correlation with the 2nd 10m (r=.793, p<.01), with the 4th 10m (r=.948, p<.001). However, there is no significant correlation with the 3rd 10m (r=.347, p=.327), the 5th 10m (r=.553, p=.097) and the 6th 10m (r=.500, p=141). The 2nd 10m had positive correlation with the 3rd 10m (r=.691, p<.05), with the 4th 10m (r=.832, p<.01), the 5th 10m (r=.740, p<.05) and the 6th 10m (r=.865, p<.001). Also, the results showed that the 3rd 10m correlated with the 5th 10m (r=.774, p<.01) and with the 6th 10m (r=.924, p<.001). There is no significant correlation with the 4th 10m (r=.473, p=.168). The 4th 10m correlated with the 5th 10m (r=.689, p<.05). There is no significant correlation with and the 6th 10m (r=.615, p=.59). Also, the 5th 10m correlated with the 6th 10m (r=.859, p=001).

Anthropometrics: The Pearson correlation analysis revealed that body height has high positive correlation which is statistically significant with body mass (r=.774, p<0.1), arm length (r=.850, p<.01), Mean leg length (r=.819, p<.01), SL (r=.788, p<.01). Also, the results show a high negative correlation with Body Fat (r=-.752, p<.05), with SF (r=-.787, p<.01), CT (r=-.680, p<.05), 3rd 10m (r= -.663, p<.05), 4th 10m (r=-.653, p.05) and the 6th 10m (r=-.730, p<.05).

Pearson correlation analysis shows that Kg had a high negative correlation with Body Fat (r=-.879, p=.001), total time in 60m (r=-.850, p<.01), SF (r=-.734, p<.05), CT (r=-.744, p<.05), CON CT (r=-.742, p<.05), FT (r=.-793, p<.01), the 1st 10m (r=-.703, p<.05), the 2nd 10m (r=-.913, p<.001), the 3rd 10m (r=-.822, p<.01), the 4th 10m(r=-.855, p<.01), the 5th 10m (r=-.874, p=.001) and the 6th 10m (r=-.849,

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p<.01). However, results show high positive correlation between kg and SL (r=.719, p<.05).

The results also shows that BMI has a high negative correlation with FT (=-.713, p<.05).

Arm Length has a high positive correlation with mean leg length (r=.862, p=.001).

Body Fat has a high positive correlation with total time in 60m (r=.829, p<.01), CT (r=.706, p<.05), CON CT (r=.706, p<.05), FT (r=.784, p<.01), the 1st 10m (r=.722, p<.05), the 2nd 10m (r=.844, p<.01), the 3rd 10m (r=.892, p<.001), the 4th 10m(r=.782, p<.01), the 5th 10m (r=.812, p=.01) and the 6th 10m (r=.831, p<.01).

One-way repeated measures ANOVA

1st Trial

One-way repeated measures ANOVA was used to test whether there is significant main effect between the 1st 10m, the 2nd 10m, the 3rd 10m, the 4th 10m, the 5th 10m and the 6th 10m.

The results show that there is a significant main effect between every 10m (F(5,45)=2180.15, p<.001). LSD test was used to determine in which parts of the 60m there were differences. The results show that the participants at 1st 10m (M=2417±13.8) had slower time compared to the 2nd 10m (M=1336±86.05), the 3rd 10m (M=1223±92.62), the 4th 10m (M=1213±101.88), the 5th 10m(M=1216±1014.23) and the 6th 10m(M=1198±113.61). Also, the results show that the 2nd 10m is slower than all the others, except the 1st 10m, in every 10m during 60m sprint. Also, the 3rd 10m is slower than the 6th 10m (graph 6).

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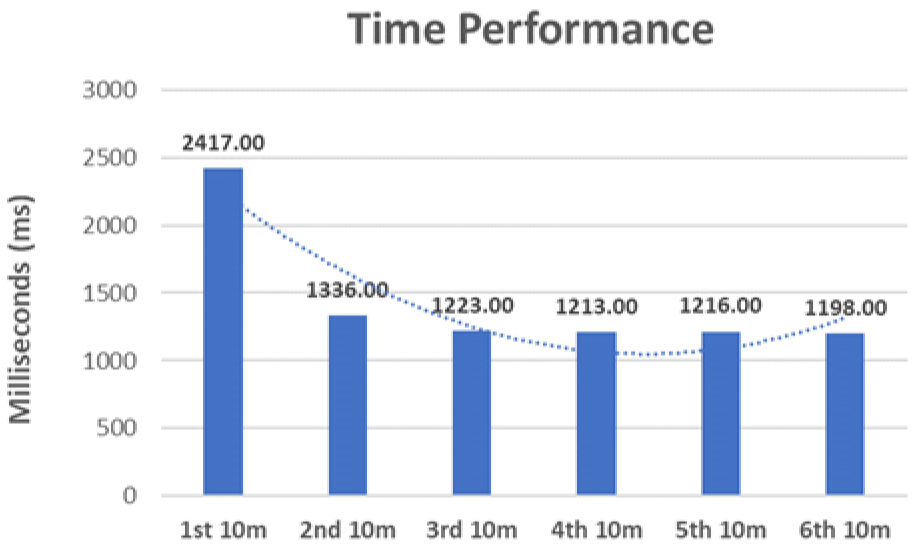

Graph 6: Time performance during all 10m sections.

DISTANCES (m)	TIME (sec)	AVERAGE SPEED (m/s)
10	2.41	4.14
20	3.75	5.3
30	4.97	6.03
40	6.18	6.4
50	7.4	6.7
60	8.6	6.97

Table 2: Mean time of athletes in every 10m during 60m sprint.

Stride frequency (SF): The results of one-way repeated measures ANOVA showed that there was a significant main effect of SF in every 10m ($F(1,9)=663.24$, $p<.001$). LSD test showed that there was a difference in SF during all the 10m distances. The results show that the participants at the 1st 10m (M=7.71±.40) had higher stride frequency than the 2nd 10m (M=5.68±.44), the 3rd 10m (M=5.37±.39), the 4th 10m (M=4.97±.30), the 5th 10m(M=5.06±.42) and the 6th 10m (M=5.01±.42). Also, the results show that the 2nd 10m had higher stride frequency than all the other parts, except the 1st 10m, in every 10m during the 60m sprint. Also, the 3rd 10m had higher stride frequency than the 4th 10m, the 5th 10m and the 6th 10m (graph 7).

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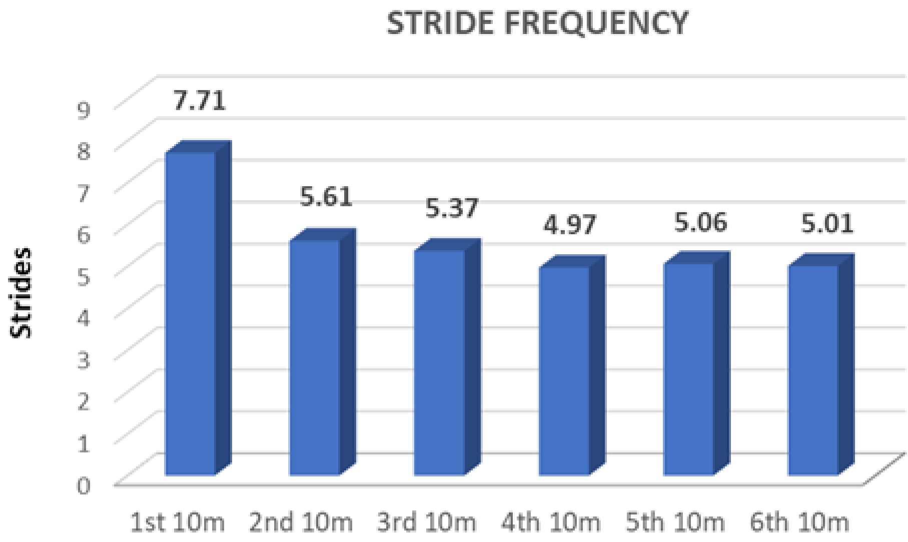

Graph 7. Stride frequency every 10m during a 60m sprint.

Stride Length (SL): The results of one-way repeated measures ANOVA showed that there was a significant main effect of SL in every 10m ($F(1,9)=352.4$, $p<.001$). LSD test showed that there was difference in SL during every 10m distance. The results show that the participants at the 1st 10m ($M=1.3\pm.70$) had smaller SL than the 2nd 10m ($M=1.77\pm.14$), the 3rd 10m ($M=1.87\pm.13$), the 4th 10m ($M=2.02\pm.13$) the 5th 10m($M=1.99\pm1.64$) and the 6th 10m ($M=2.00\pm.16$). Also, the results show that the SL at the 2nd 10m was smaller than all the other parts, except the 1st 10m, in every 10m during 60m sprint. Also, the SL at the 3rd 10m was smaller than the 4th, 5th and the 6th 10m. At the 4th 10m SL was longer than the 1st 10m, 2nd and the 3rd 10m (graph 8).

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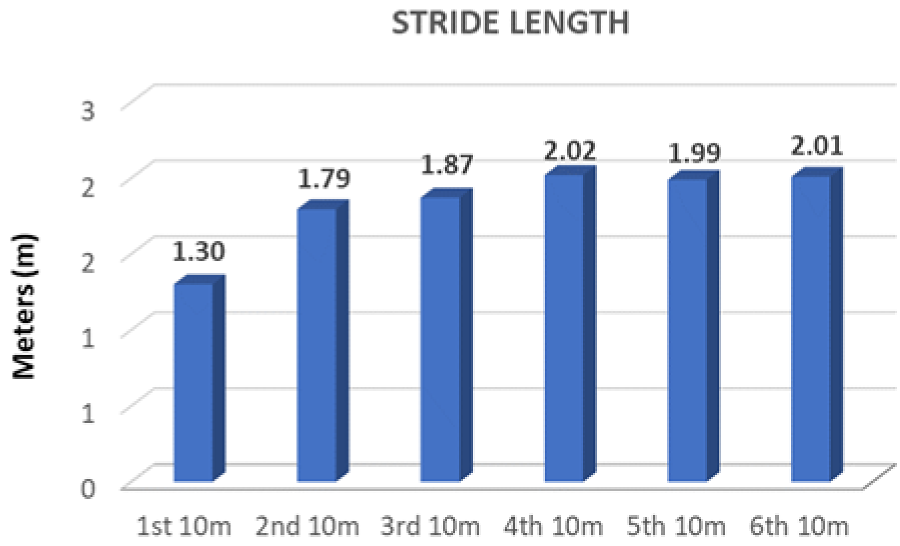

Graph 8. Stride length every 10m during a 60m sprint.

Total Contact Time CT: The results of one-way repeated measures ANOVA showed that there was a significant main effects of total CT and every 10m ($F(5,45)=12.48$, $p<.001$). LSD test showed that there was difference between total CT and every 10m distances. The results show that the participants at the 1st 10m (M=145.25±12.93) had slower CT than the 2nd 10m (M=127.82±9.0) the 3rd 10m (M=121.83±11.46) the 4th 10m (M=120.66±8.28) the 5th 10m(M=124.66±15.95) and the 6th 10m (M=126.67±10.74). Also, the results show that the total CT at the 2nd 10m was slower than the 4th 10m. Also, the total CT at the 4th 10m was slower than the 6th 10m (graph 9).

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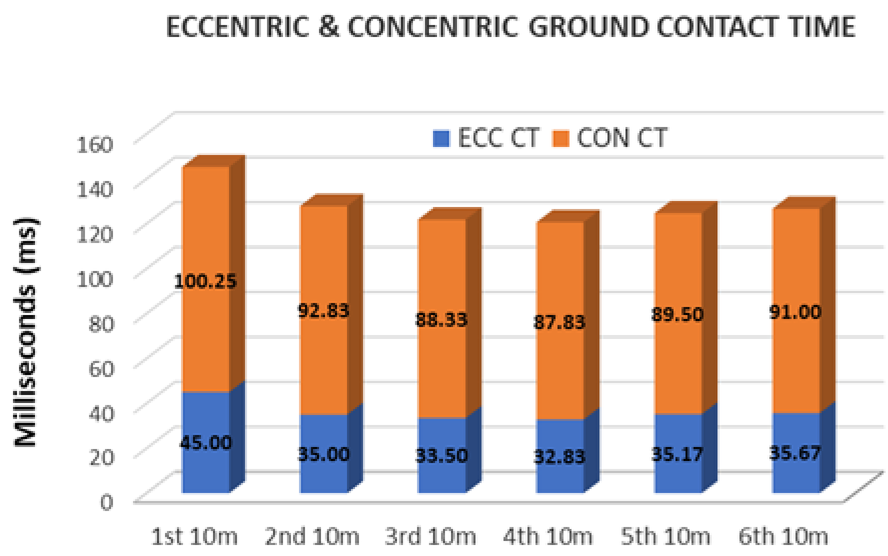

Graph 9. Eccentric and concentric ground contact time every 10m during a 60m sprint (ECC CT = Eccentric ground contact time, CON CT = concentric ground contact time).

Concentric contact time (CON CT): The results of one-way repeated measures ANOVA showed that there was a significant main effect of CON CT and every 10m (F(5,45)=4.766, p<.001). LSD test showed that there was difference between CON CT and every 10m distance. The results show that the participants at 1st 10m (M=100.25±14.21) had slower CON CT than the 3rd 10m (M=88.33±7.79) the 4th 10m (M=87.83±6.57) the 5th 10m(M=89.50±12.58) and the 6th 10m (M=90.99±11.41). Also, the CON CT at the 2nd 10m (M=92.83±83.0) was slower than the 4th (M=87.83±6.57).

Eccentric contact time (ECC CT): The results of one-way repeated measures ANOVA showed that there was a significant main effect of ECC CT and every 10m (F(5,45)=8.46 , p<.001). LSD test showed that there was difference between ECC CT and in distances in every 10m. The results show that the participants at 1st 10m (M=45±9.79) had slower ECC CT than the 2nd 10m (M=35.01±5.94), the 3rd 10m (M=33.5±7.14), the 4th 10m (M=32.83±4.59), the 5th 10m (M=35.17±7.14) and the 6th 10m (M=35.67±5.05).

Flight time (FT): The results of one-way repeated measures ANOVA showed that there was a significant main effect of FT and every 10m (F(5,45)=26.05, p<.001). LSD test showed that there was difference between FT and in distances in every 10m. The results show that the participants at the 1st 10m (M=168.59±18.54)

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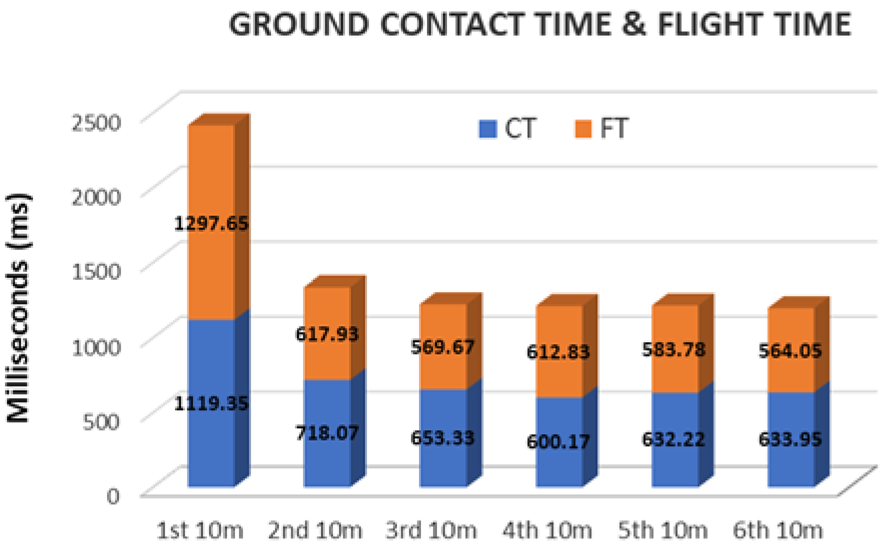
had longer FT than the 2nd 10m ($M=108.01\pm14.41$), the 3rd 10m ($M=106.89\pm16.45$), the 4th 10m ($M=123.34\pm8.09$), the 5th 10m ($M=115.86\pm12.31$) and the 6th 10m ($M=113.28\pm20.52$). Also, the results show that the FT at the 2nd 10m was shorter than the 4th 10m. Also, the FT at the 3rd 10m was shorter than the 4th 10m (graph 10).



Graph 10. Ground contact time and flight time every 10m during a 60m sprint (Total CT = ground contact time, FT = flight time).

3rd Trial

Time (T): The results of one-way repeated measures ANOVA showed that there was a significant main effect between T and in every 10m ($F(5,45)=1564.04$, $p<.001$) of 60m sprint. LSD test showed that there was a difference between T and in distances in every 10m. The results show that the participants at the 1st 10m ($M=2379\pm118.74$) was slower than the 2nd 10m ($M=1340\pm74.28$), the 3rd 10m ($M=1237\pm88.83$), the 4th 10m ($M=1216.97\pm96.63$), the 5th 10m ($M=1210\pm103.17$) and the 6th 10m ($M=1233\pm121.02$). Also, the results shows that the 2nd 10m was slower than all the other parts in every 10m during 60m sprint (graph 11).

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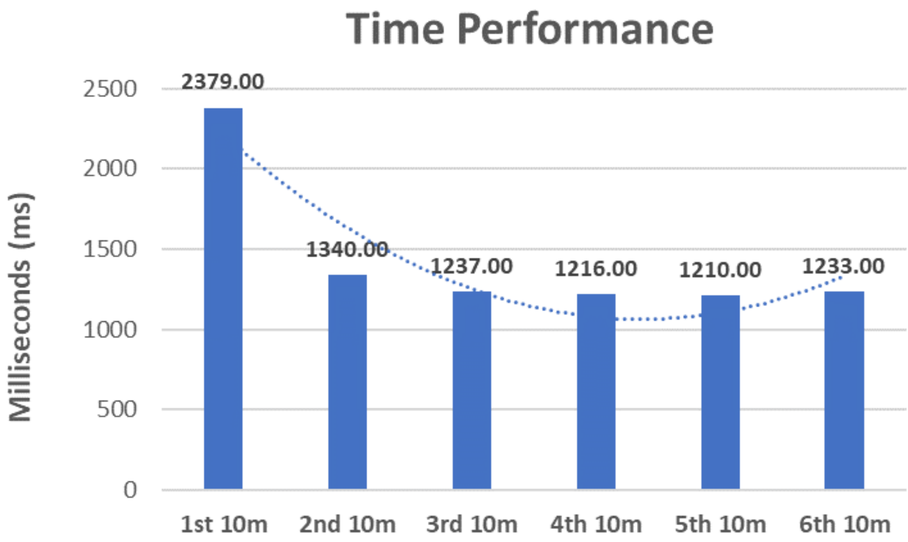
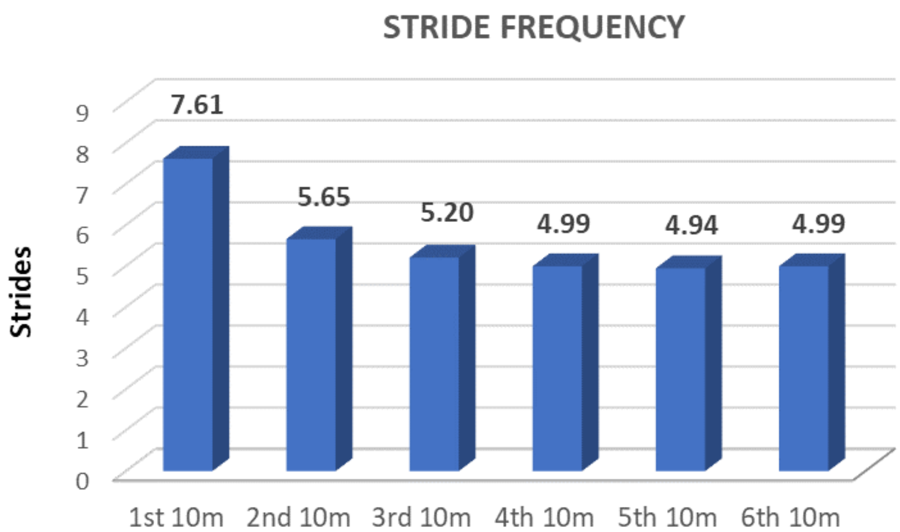


Graph 11. Time performance during all 10m sections.

Stride frequency (SF): The results of one-way repeated measures ANOVA showed that there was a significant main effect of between SF and in every 10m (F(5,45)=140.2, p<.001). LSD test showed that there was a difference between SF and in distances in every 10m. The results show that the participants at the 1st 10m (M=7.61±.39) had more stride frequency than the 2nd 10m (M=5.65±.53), the 3rd 10m (M=5.2±.27), the 4th 10m (M=4.99±.43), the 5th 10m (M=4.94±.39) and the 6th 10m (M=4.99±.40). Also, the results shows that the 2nd 10m had more stride frequency than all the other parts during 60m sprint (graph 12).



Graph 12. Stride frequency in every 10m during a 60m sprint.

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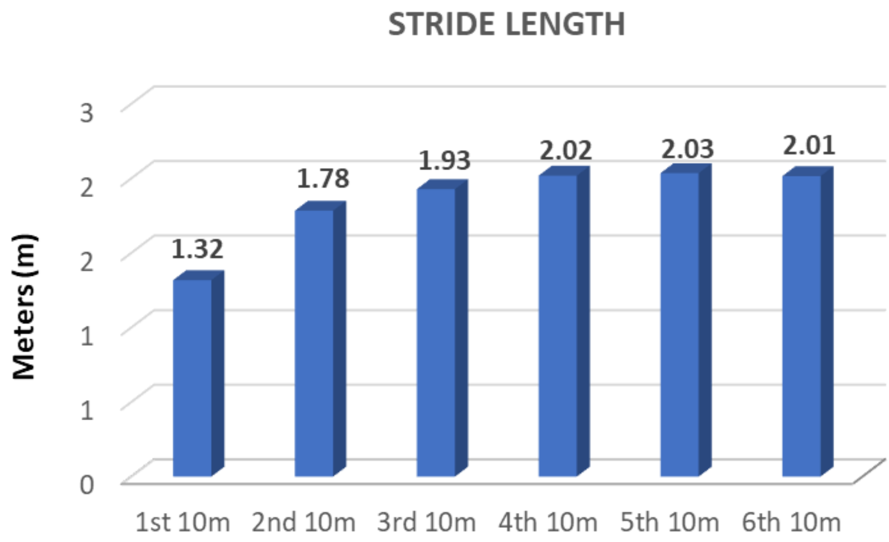
Stride Length (SL): The results of one-way repeated measures ANOVA showed that there was a significant main effect of SL in every 10m ($F(5,45)=83.69$, $p<.001$). LSD test showed that there was a difference between SL and every 10m distance. The results show that the participants at the 1st 10m (M=1.31±.07) had smaller SL than the 2nd 10m (M=1.78±.16), the 3rd 10m (M=1.93±.97), the 4th 10m (M=2.35±.15) the 5th 10m(M=2.04±.15) and the 6th 10m (M=2.02±.15). Also, the results shows that the SL at the 2nd 10m was smaller than all the other parts during 60m sprint. Also, the SL at the 3rd 10m was smaller than the 5th 10m (graph 13).



Graph 13. Stride length in every 10m during 60m sprint.

Total Contact Time CT: The results of one-way repeated measures ANOVA showed that there were significant main effects of total CT and every 10m ($F(5,45)=18.5$, $p<.001$). LSD test showed that there was difference between total CT and every 10m distances. The results show that the participants at the 1st 10m (M=151.5±13.7) had slower CT than the 2nd 10m (M=128.67±13.42) the 3rd 10m (M=125.49±15.32) the 4th 10m (M=125.49±15.32) the 5th 10m(M=127.82±17.01) and the 6th 10m (M=128.67±15.57) (graph 14).

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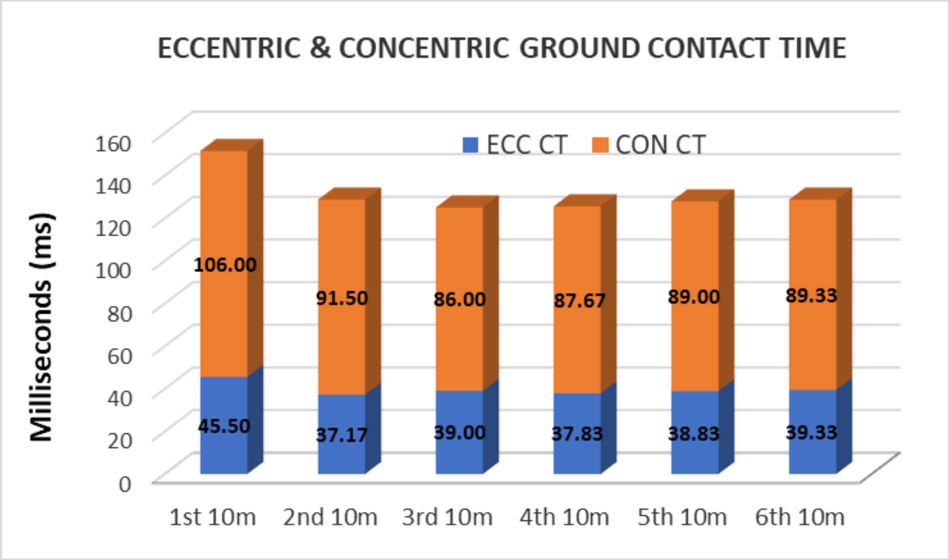

Graph 14. Eccentric and concentric ground contact time in every 10m during a 60m sprint (ECC CT = Eccentric ground contact time, CON CT = concentric ground contact time).

Concentric contact time (CON CT): The results of one-way repeated measures ANOVA showed that there was a significant main effect of CON CT and every 10m (F(5,45)=19.04, p<.001). LSD test showed that there was difference between CON CT and every 10m distance. The results show that the participants at the 1st 10m (M=106.00±11.38) had slower CON CT than the 2nd (M=91.5±9.82), the 3rd 10m (M=86.00±8.99) the 4th 10m (M=87.68±11.74) the 5th 10m(M=89.01±9.65) and the 6th 10m (M=89.33±11.41).

Eccentric contact time (ECC CT): The results of one-way repeated measures ANOVA showed that there was a significant main effects of ECC CT and every 10m (F(5,45)=8.46, p<.05). LSD test showed that there was a difference between ECC CT and in distances in every 10m. The results show that the participants at 1st 10m (M=45.5±10.19) had slower ECC CT than the 2nd 10m (M=37.16±10.24) and the 6th 10m (M=39.34±8.82).

Flight time (FT): The results of one-way repeated measures ANOVA showed that there was a significant main effect of FT and every 10m (F(5,45)=13.92 , p<.001). LSD test showed that there was difference between FT and in distances in every 10m. The results show that the participants at the 1st 10m (M=161.77±13.84) had longer FT than the 2nd 10m (M=109.92±17.13), the 3rd 10m (M=113.21±18.27),

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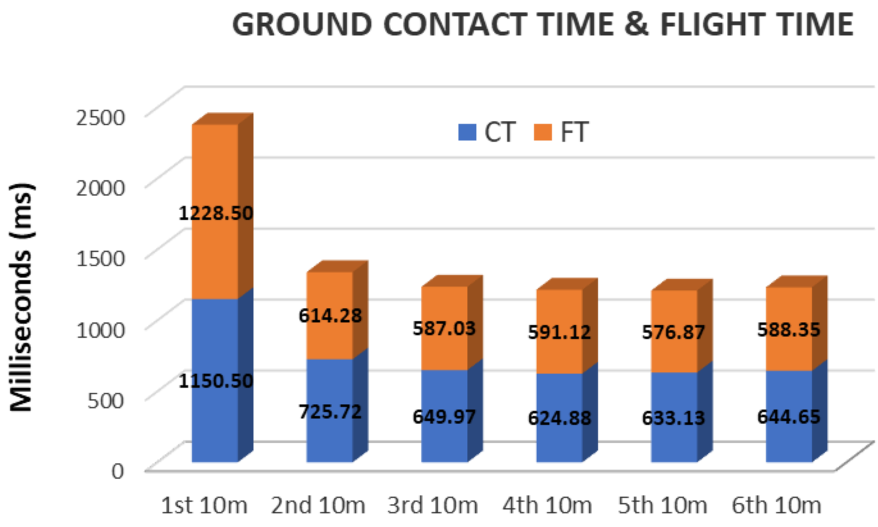
the 4th 10m (M=119.92±23.91), the 5th 10m (M=117.59±15.27) and the 6th 10m (M=118.69±19.81). Also, the results show that the FT at the 2nd 10m was shorter than the 5th 10m. (graph 15).



Graph 15. Ground contact time and flight time every 10m during a 60m sprint (Total CT = ground contact time, FT = flight time)

Paired sample t test

Paired t test was used to examine whether there were significant statistical differences in 60m between the 1st and the 3rd trial. Results show that there were significant differences only in the total time of 60m between the 1st and the 3rd trial ($t_6=-3.873$, $p<.01$) (graph 18). Also, there were differences in other kinematic characteristics which however were not statistically important (graph 16, graph 17, graph 19).

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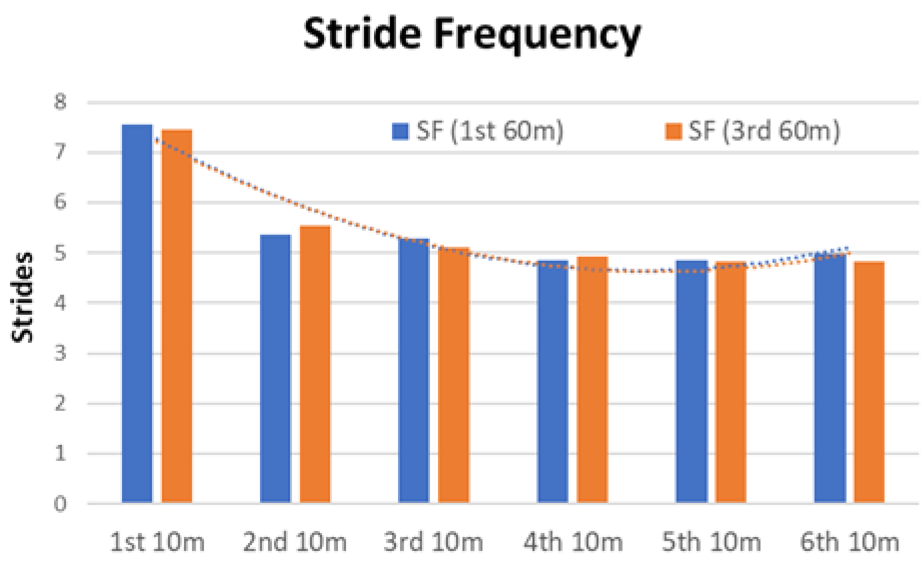

Graph 16. Differences in stride frequency (SF) every 10m between the 1st and the 3rd 60m sprint.

Graph 17. Differences in stride length (SL) every 10m between the 1st and the 3rd 60m sprint.

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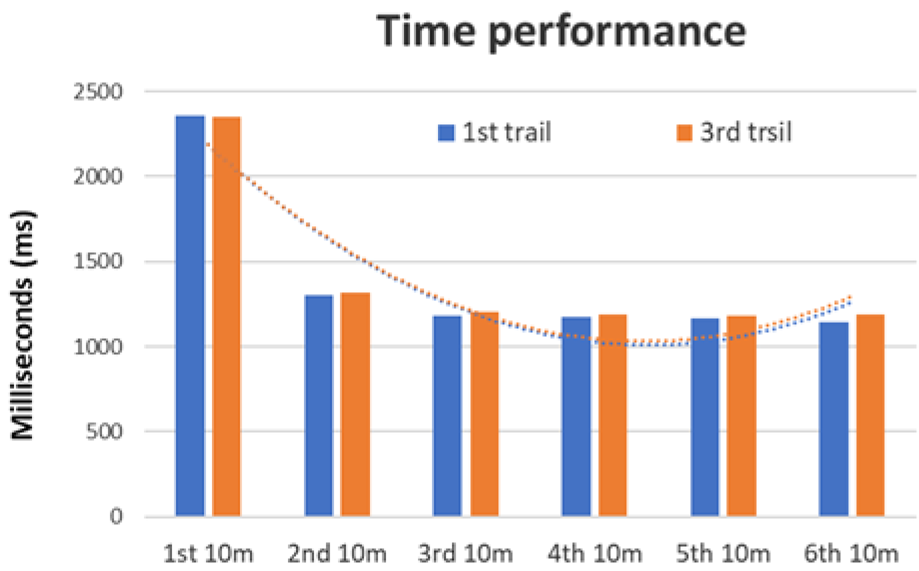
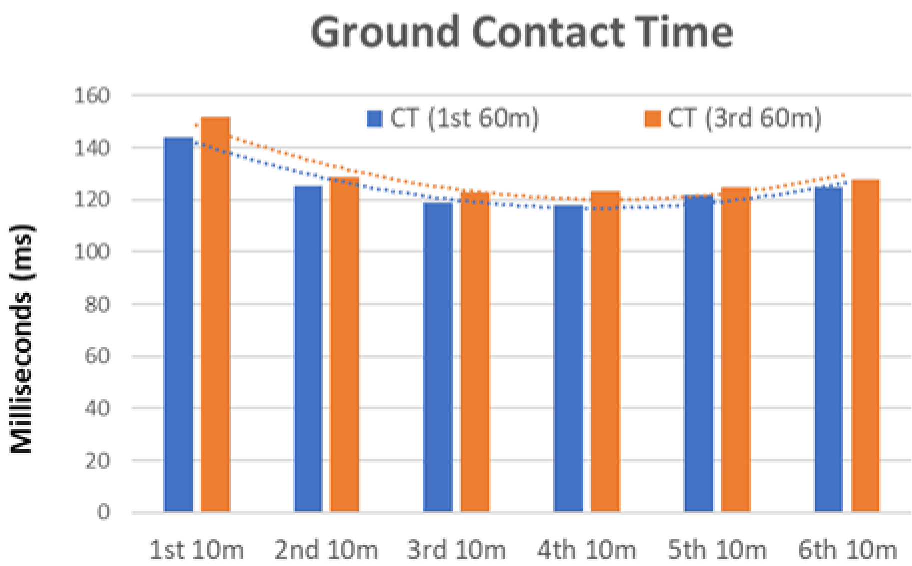


Graph 18. Differences in time performance every 10m between the 1st and the 3rd 60m sprint trail.



Graph 19. Differences in ground contact time every 10m between the 1st and the 3rd 60m sprint trail.

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DISCUSSION

The ability to monitor the kinematic characteristics of an athlete during a maximum sprint performance is crucial. In existing scientific literature there is not enough evidence on kinematic characteristics during a 60m sprint performance. The purpose of this study was to examine how kinematic variables (speed, SL, SF, CT, ECC CT and CON CT and FT) affect the different sprint phases and the final performance during a 60m sprint.

Time Performance

Our research has been conducted in sections. Photocells were located every 10 meters, so as to calculate the athlete's speed in more than one sections. In this way we can further analyze the behavior of kinematic characteristics and their influence on acceleration, maximum speed and maintenance of speed during sprint running.

According to the literature faster male and female track and field athletes achieved maximum velocity ~12m/sec^{-1} and ~11 m/sec^{-1}, respectively (Slawinski et al., 2017). Acceleration differentiates according to the athletes' performance level. High level athletes achieved maximum velocity at sprinting after those who had slower times (Arsac & Locatelli, 2002; Nagahara et al., 2014; Taylor & Beneke, 2012). The results of the present study confirm that maximum velocity is achieved after 50m. Chatzilazaridis et al. (2012) found that no professional athlete achieves maximum velocity at ~30m. In our study, we observed that the athletes had great acceleration until 30m, small acceleration at 40m and 50m and reached maximum velocity at 50m to 60m. According to our results those athletes who were faster at 60m were also faster in all phases of sprint. (Table 2)

Stride Frequency and length

As we have already mentioned, the athlete's speed is the result of SL and SF. Therefore, the athlete's goal is to improve the SL while keeping the SF relatively consistent (Mackala, 2007). We have indicated a great and negative correlation (r=-.997, p=.000) between SL and SF as also other investigators have proved (Nagahara et al. 2014), (Weyand et al. 2000). Improving one of the two has an impact on the other. Weyand et al. (2000) showed that faster runners had longer SL and lower SF than the slower ones. Scientific literature supports that the phases of

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velocity have the same tendency with SL (Lockie et al., 2011). In our research we proved that SL and SF determine the good performance, with athletes having longer SL ($r=-.677$, $p=0.053$) and lower SF ($r=.646$, $p<0.05$) performing better.

We also, investigated the relationship between SL and SF in each of the sections of the 60m sprint. We observed that SF had a positive correlation with 20m, 30m, 40m and 60m, while it was gradually decreasing throughout the 60m sprint. Also, in the present study our athletes in the 1st 10m had the shortest SL (~1.3±7 strides) that was increased rapidly until 20m and then there was a gradually increase until 60m. Maximum SL was recorded at 40m (2.02±0.13m). This findings are in accordance with past researchers that found surges in SL during the first acceleration phase (Chatzilazaridis et al., 2012; Čoh et al., 2006; Nagahara et al., 2014).

Consequently, according to these findings for a better performance in 60m sprint to be achieved, a combination of SL and SF training is required. For example, if athletes have slow acceleration in the 30m, they must improve their stride frequency. According to previous studies, SL at the end of the acceleration phase in male and female professional sprinters ranged between 2.3–2.8m and 2.05–2.3m, respectively (Graubner, 2011; Rabita et al., 2015). Nagahara et al. (2014) have proved that high frequency is important at first 5m, the longer SL is important for 5m to 30m, and in the final section it is important to improve one of them. In our study we noticed that fast athletes after 30m at the end of acceleration, maintained the same SL and lower SF than the previous sections. In the present study we also found that total time in 60m correlated with high SF in 1st section (~7.71 strides) which decreases gradually until the end of acceleration, while SL increases gradually from the 2nd section (~1.79m) until the 5th section (~2.02m) of 60m sprint.

Other studies did not reveal significant a main effect between SL and the total performance (Debaere et al., 2013; Salo et al., 2011). Also, SL is correlated with the athlete's height, which is consistent with our research, with the increase in the power required for each limb to begin its flight time and the decrease in absorption power during the contact phase (Thorstensson & Roberthson, 1987). The correlation between SL and the last two parameters was not measured in our study as the forces were not taken into account in our research. Moreover, SL and SF are correlated with the range of motion of the lower limbs (Novacheck, 1998).

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Professional athletes chose to improve different combinations of SL and SF. Athletes with maximum strength and power chose to improve SL whereas athletes with better coordination abilities and explosive power chose to enhance the SF (Salo et al., 2011).

Ground Contact Time

According to previous studies professional athletes at maximum velocity achieved the quicker CT. In the 1st step CT is 150-200ms and at maximum velocity decreases in half (Čoh et al., 2006; Ettema et al., 2016; Haugen et al., 2019; Nagahara et al., 2014). In our study we also found that the quicker CT was at the 4th 10m (M=120.66±8.28), at the beginning of the maximum velocity phase whereas the slower was at the 1st 10m (M=145.25±12.93) and especially in the 1st step. Haugen et al. (2018), also found that the variation of CT defines the total time of sprint because it is strongly associated with SF. That is why many coaches focus on enhancing SF. According to our study athletes who had quick CT were faster, they had low frequency, long SL, short CON CT and faster 10m sections during the 60m sprint.

Also, they indicate that those who had faster speed applied greater support forces to the ground. Although longer strides are effective for a better performance because they increase the available time to apply GRF, athletes and their coaches avoid utilising it because it decreases the ability of the active muscles to apply the necessary ground force in preparation for the next stride. (Farley & González, 1996).

According to previous studies runners achieved faster times by applying greater forces to the ground and not by increasing their frequency (Weyand et al., 2000).

Flight Time

Many investigators have proved that FT does not affect the peak of CT during sprint, neither at fast athletes nor at slower ones (Chatilazaridis et al., 2012; Kutlu et al., 2017; Otsuka et al., 2016). In the present study, we noticed that the peak of CT during the 60m sprint, was not correlated with FT (r=.600, p=.067). Numerous studies have proved that FT increases gradually throughout acceleration (Čoh et al., 2006; Debaere et al., 2013; Ettema et al., 2016; Haugen et al., 2018; Nagahara et

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al., 2014; Rabita et al., 2015). On the other hand, in our study we found that FT during the 1st phase of acceleration is shorter, but at the end of acceleration (40m) we have the longer FT in comparison with the previous sections. Also, we found that the slower athletes had also longer FT and accordingly faster athletes had shorter FT.

Concentric and Eccentric Phase of the quadricep

Athletes in every step apply a landing and a push off action. Previous studies have proved that a balance between those two actions brings better performances (Morin et al., 2015). So, scientific literature has divided ground CT in braking (ECC) and propulsive (CON) phases (Haugen et al., 2019). Bezodis et al. (2008) supports that the ability to minimize the braking phase increases the ability to minimize the propulsive phase.

In the present study we found that CON CT decreases gradually after 20m. We have the shorter CT between 30m and 60m. In contrast with CON CT, the ECC CT decreased after 10m. In our study also, we found that the propulsive phase is strongly correlated with total CT (r=.910, p=.000) and total performance (r=.882, p=.001. According to our study if we improve the time of CON CT we will have better performance but we have not proved that there is significant correlation between ECC CT and total time. This finding is at contrast to a previous study that has found that it is beneficial to decrease during the braking phase. (Bezodis et al., 2008).

Total CT and CON CT

Each athlete’s running technique is individualised. Ground reaction forces are dependent to the way the first contact with the ground is done (Hamill, 2007). Ground reaction forces in running range from 1.5 to 2 times the body weight, but they increase depending on the speed or the increase in SL (Weyand et al., 2000). GRF are vertical, anteroposterior, and horizontal. Generating high vertical and horizontal forces has a great impact on the performance in sprinting. To achieve the best possible acceleration during the acceleration phase the athlete is required to have maximum vertical force and maximum horizontal propulsive force (Morin, 2011). In our research we were not able to prove that because forces were not

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measured, however we indicated a great correlation between the total CT and the CON CT which is greatly associated with total performance. The concentric phase time is the phase where horizontal propulsive forces where applied. We also proved that the eccentric phase time where the absorption forces are applied, has no significant correlation with total CT and the time performance, meaning that a good performance in sprinting is achieved not only with the athlete's longer SL (increase in vertical power) but also by achieving high horizontal power (Morin, 2011).

CON CT has a definitive role in all the phases during the 60m sprint as well as the final performance. According to the results CON CT was gradually decreasing throughout the total acceleration phase. Athletes with slow CON CT had long SL and low SF resulting in a better performance. That is possibly due to the propulsive phase where horizontal forces are applied. As it was proved in past studies (Morin, 2011) the higher the horizontal forces applied the better is the performance achieved.

Anthropometric Characteristics

Previous studies have indicated the relationship between anthropometric characteristics in time performance during sprint (Van Schenau et al., 1994). In our study we show that taller athletes were faster, and they had longer SL, low SF, short CT and faster times after acceleration (>30m) until the end of the sprint. Van Schenau et al. (1994), has proved that athletes with longer limbs can extend longer by providing greater horizontal propulsion. In the present study we did not find significant correlation between the mean of leg length and SL (r=.622, p=.055) or SF (r= -.612, p=.060) but the tendency was the same as in previous studies. Also, our study reveals that slower athletes had more body+ fat (BF). In contrast with previous studies, we did not find significant correlation between BF and SF (r=630, p=.051). In our study we found that faster athletes who had lower BF had quicker CT (r=.706, p= 0.022) and the propulsive phase (r=.647, p=0.043) and accordingly they had faster sections during the 60m sprint. Athletes with more body mass were slower and had slower times during the 60m sprint, higher SF, slower CT and CON CT, short SL and long FT.

Differences between 1st and 3rd trial

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In the 3rd trial results indicated that after fatigue, FT is longer and all other parameters are affected, but there are no statistically significant correlations. Results show that the 1st 10m is slower than all the other 10m marks in the 60m sprint and that the 2nd is slower than the 3rd 10m, 4th 10m, 5th 10m and the 6th m. A fact that is confirmed by other studies.

Conclusion

Our study supports that kinematic characteristics affect the total performance in the 60m sprint and specifically shows that the total time in 60m is affected by SF, SL, FT, ground CT and CON CT.

Our results indicate that athletes with faster times have faster times during all 10m sections during the 60m sprint. Additionally, those athletes who had better performances at 60m had also low SF, short FT, and long SL, while ground CT and the time of CON CT was decreasing during the 60m sprint.

Consequently, as SL becomes longer, ground CT, SF, FT decreases and the athlete's performance improves. As the values are inversely proportional athletes with low frequency had also quick ground CT. In addition, a fast athlete has also quick ground CT and CON CT. The total ground CT of a fast athlete is due to a faster CON CT. No significant differences were found in any of the sprint parameters and ECC CT during 60m performance. Also, the athletes with quick ground CT were faster.

The element that makes the difference in sprint performance is the short concentric phase. Probably, the shorter concentric phase is produced from the elastic energy that is produced during the eccentric phase. A short concentric phase then initiates short ground contact time, long SL, short SF and consequently a better sprint performance. Also, a short concentric phase during sprinting is a matter of a short SSC that is dependent on genetic genotype and the adaptations of physical training. A future investigation subject would be the causes of a fast concentric phase and how we can improve them.

In our research we attempted to find a method to evaluate in depth the parameters that influence speed by using an accelerometer devise. This method could give plenty of information to the coach and probably could be used not only to assess an athlete but also during everyday training.

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